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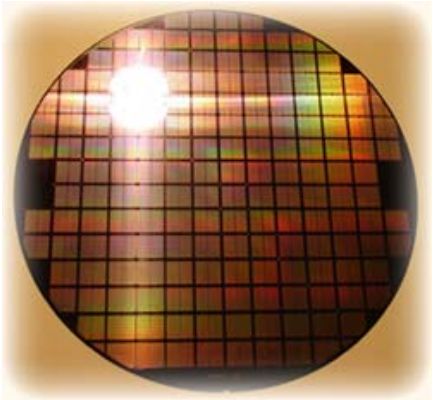
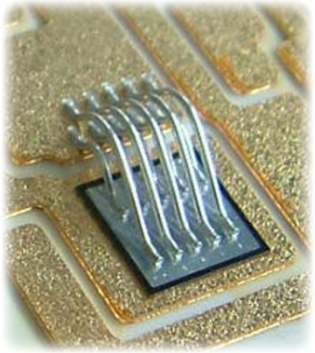
Gallium Nitride and its application to Power Conversion and Battery Management

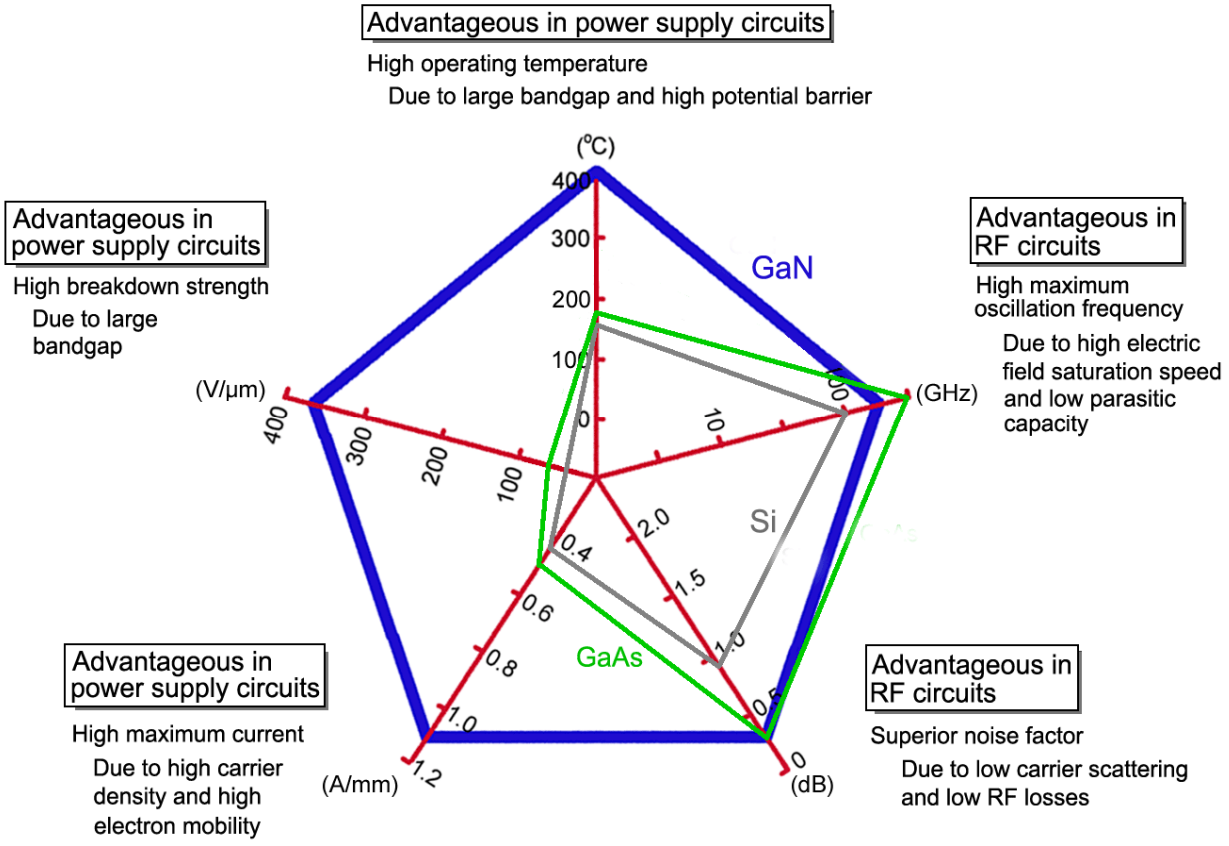
September 2009



An introduction to gallium nitride, GaN high efficiency devices, and their potential applications for power conversion and battery management



Why is GaN so special?



What problem does GaN solve?

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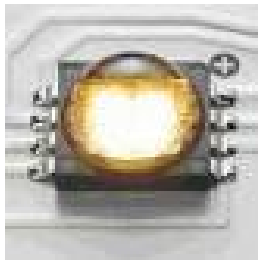
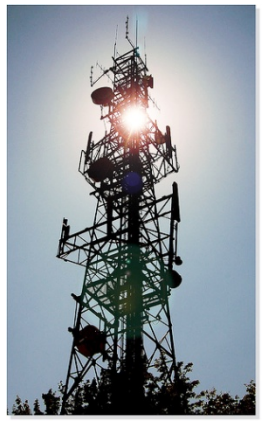
Lighting





Communications

Power conversion
& battery management

Its all about *efficiency !*

GaN Applications

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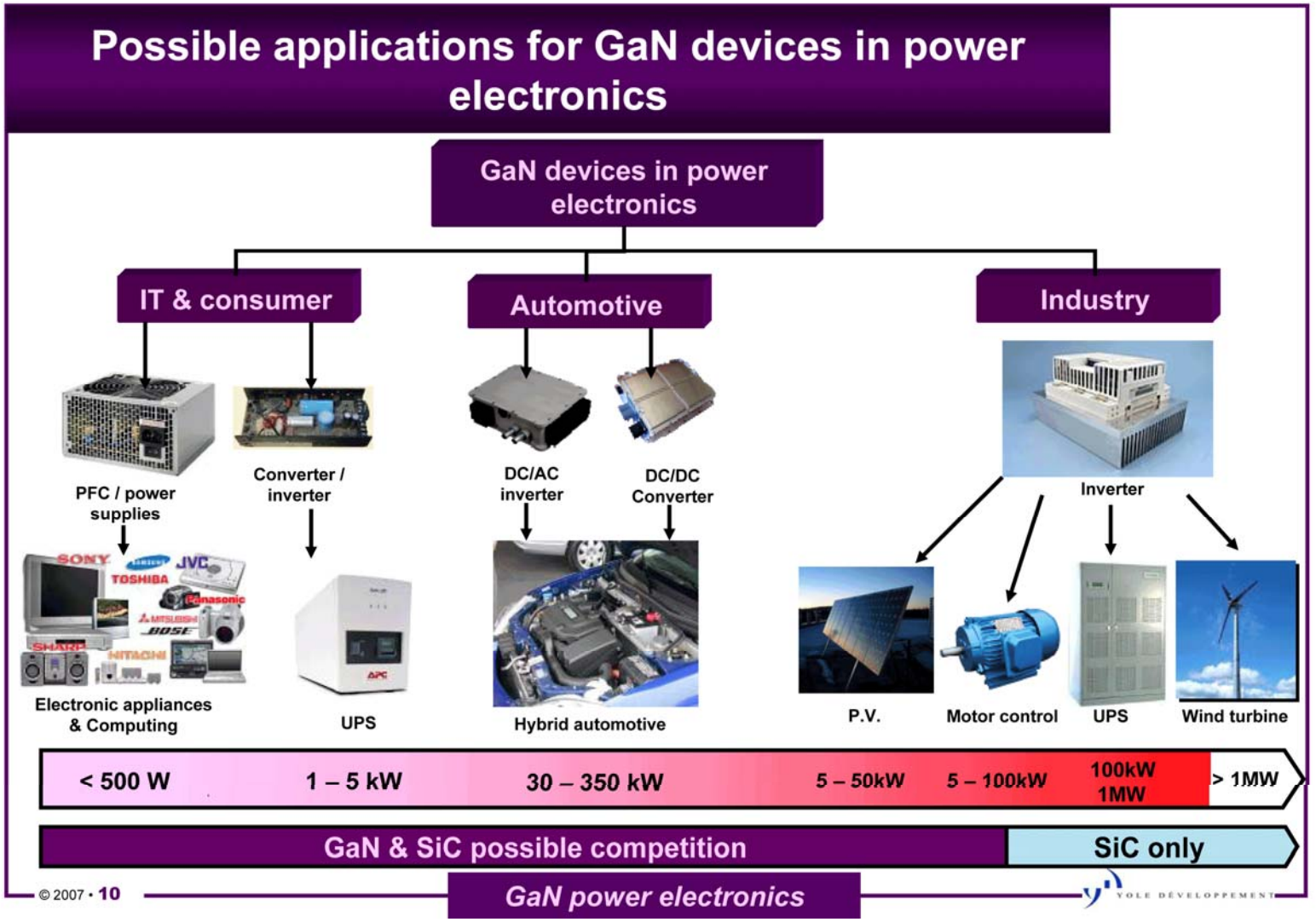

A few common questions about GaN

Where does it come from – is gallium scarce?

- By-product of aluminum production - 50 ppm of gallium in bauxite
- 15 million kg in US alone

Is it toxic?

- No

Why is it only now being developed?

- Process challenges
- Defect density

Melts at 29.8 deg C Vaporizes at 2204° C

What does this mean in practice ?

Within a year we will have –

Diodes with power handling of 200Amps and zero forward voltage drop at 10 Amps

Switching transistors with an on-resistance less than that of a copper contactor

And shortly afterwards -

Prices competitive with silicon

300°C operation

Low on-resistance GaN

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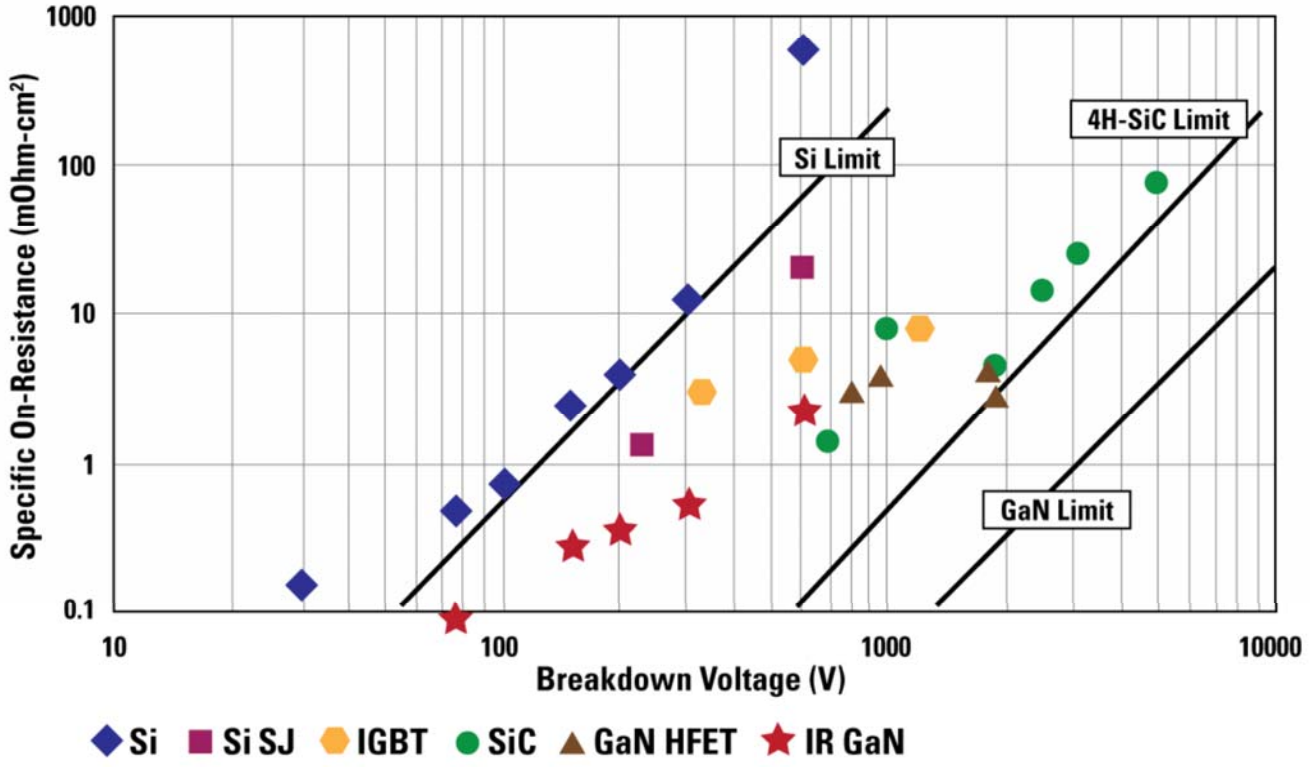
Comparison of R_{on} for Si, SiC, and GaN



What does this mean for PHEVs?

With -

- A switch with an on-resistance of 0.01 mohm = 0.1 watt loss per 100 amps
- A switching speed of < 50 picosecs = low switching losses
- An operating temperature of 300 °C = air cooling

Power conversion

Converter losses reduced from 5% to 1.5%

- typical saving 3.5kW in 100h.p. car, plus cooling system weight

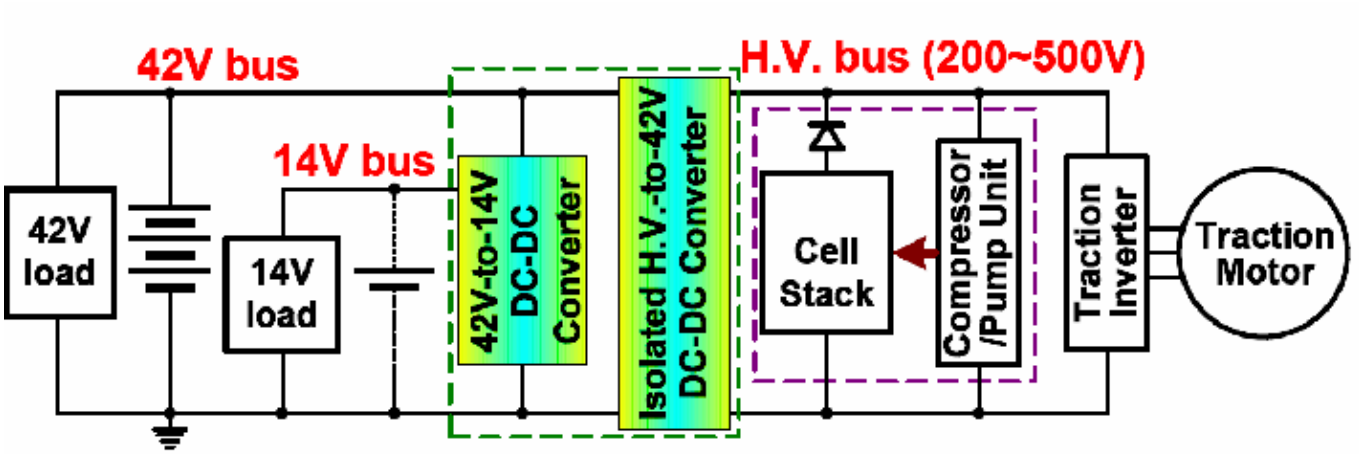
Batteries

Integrated Battery Health Management becomes viable

- Battery life extended by > 60% - 5 years to 8 years

GaN Systems objective

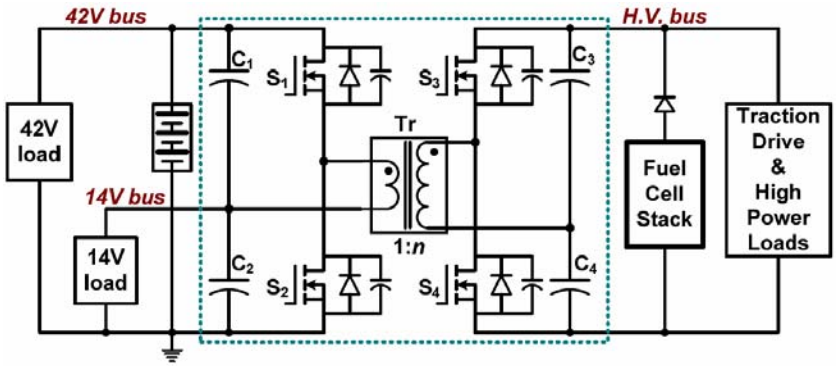
- Develop a dc-dc converter topology that provides
  - Low component count, compact, light
  - Easy power scaling capability
  - Ultra high efficiency
- Economic, robust, light
- Bidirectional power conversion of 4kW
- Highly reliable

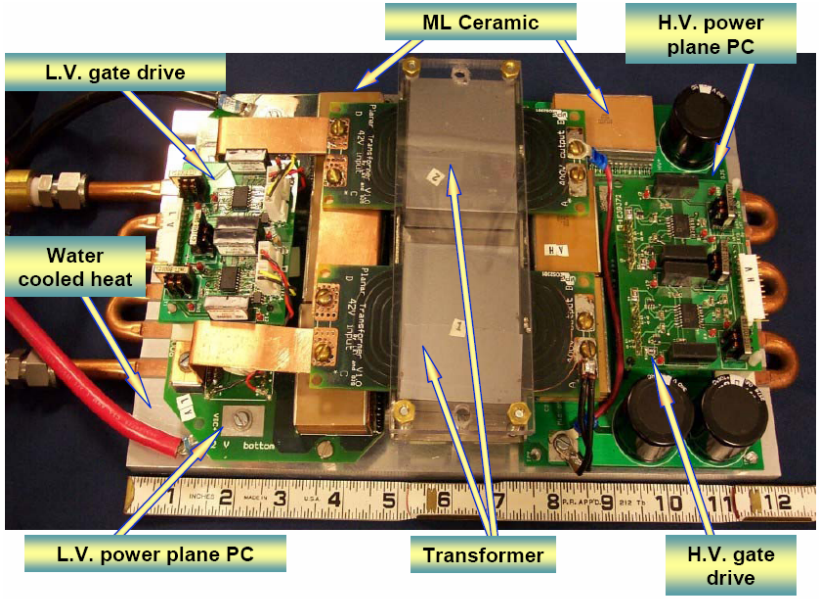


Power management in future fuel cell vehicles

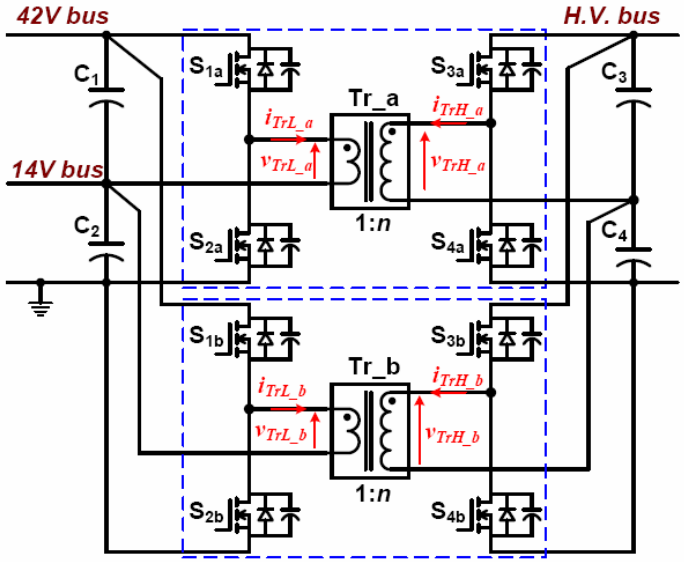
Oak Ridge National Laboratory System

- 2-kW modules to create higher power
- Basic module with Half-Bridge topology
- Si IGBT switches and SiC rectifiers
- Bidirectional power conversion





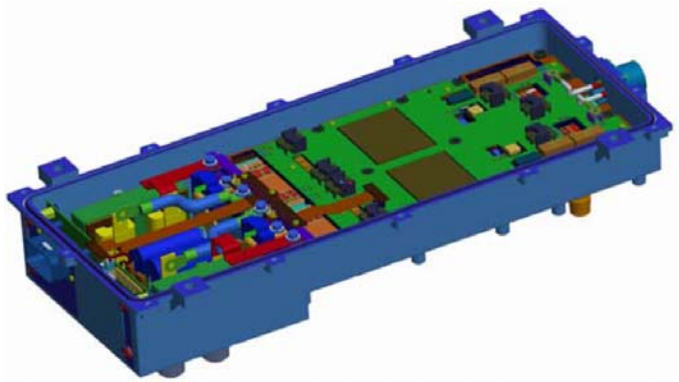
The 4-kW prototype. Footprint: 10.7 in. wide × 11.0 in. deep × 2.7 in. maximum height.

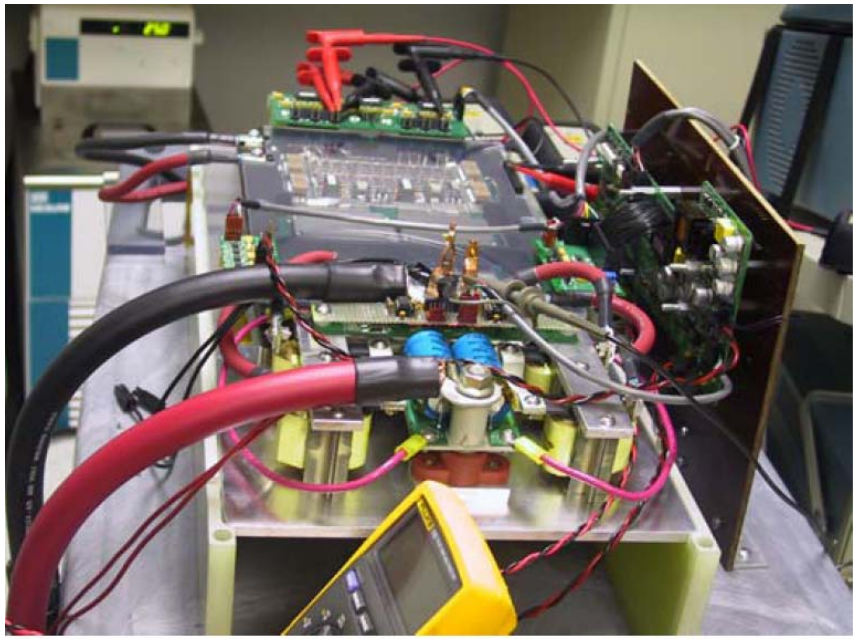


Schematic of the 4 kW dc-dc converter.

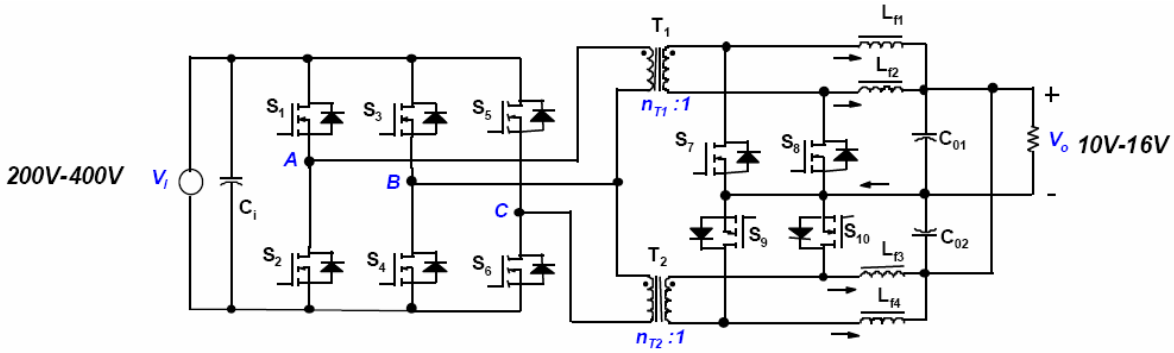
Ballard Power System

- Working temperature of 105 ˚C
- Cost target $75/1kW (not met)
- Efficiency 93%
- Reference
- Weight 7.4kg (target=6kg)





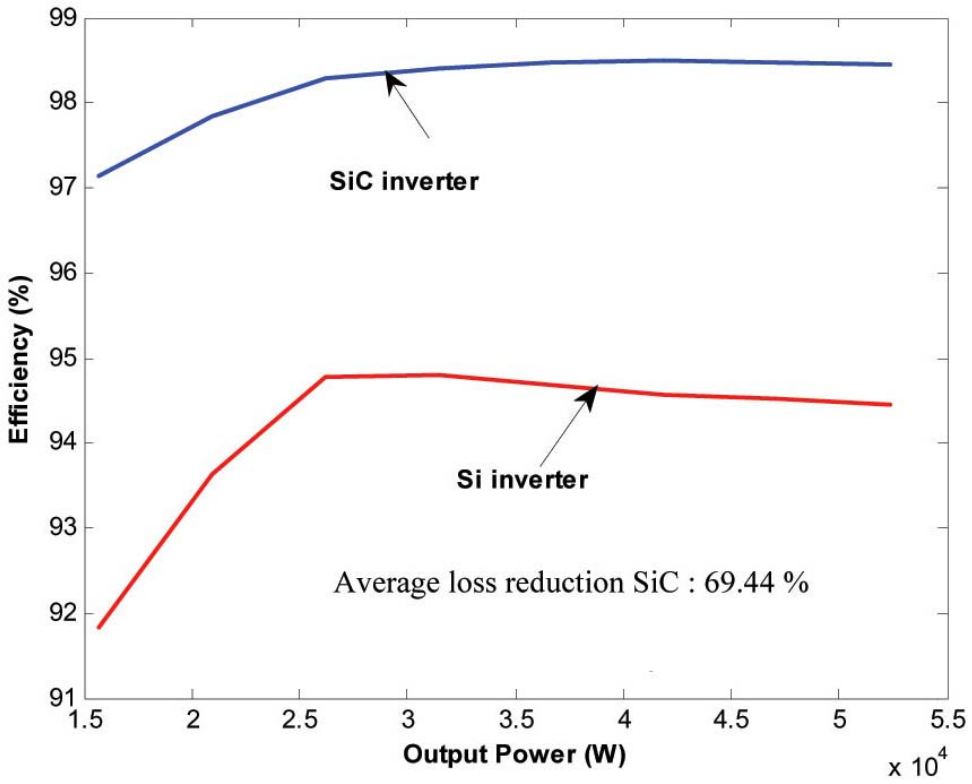
dc/dc converter under test



The novel interleaved dc/dc converter topology

Wide Band-Gap Materials vs. Silicon

- The graph illustrates the efficiency improvement resulted from using SiC devices
- Similar or better results would be achieved by GaN devices



Efficiency versus output power of two different inverters at a 200 N-m load

Green savings

SDTC Calculation assumptions:

- Car 'mileage' per year, 20,000 km/year
- PRIUS efficiency improvement using GaN - 4% = 4gm/km
- Cars/light vehicles made world wide in 2015 - 100 million
- GaN Systems market penetration, 4 Million vehicle in 2015
- = 20,000 x 4 x 2,000,000 = 160 kilotonnes
- GHGs reduced pro rata to CO_2

Reduction of GHG & pollutants as a result of using GaN Systems devices (in 2015 alone)

- CO_2 combined – 160 Kilotonnes
- CO carbon monoxide – 280 tonnes
- HC Hydrocarbons – 30 tonnes
- NOx Nitrogen oxide – 15 tonnes

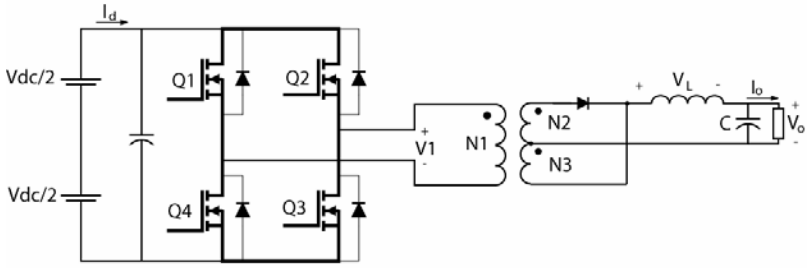
Substrate Economics

Potential GaN substrates

Size/material		Cost/cm^2
75mm silicon carbide		$9.00
100mm sapphire	$1.90	
150mm silicon		$0.11

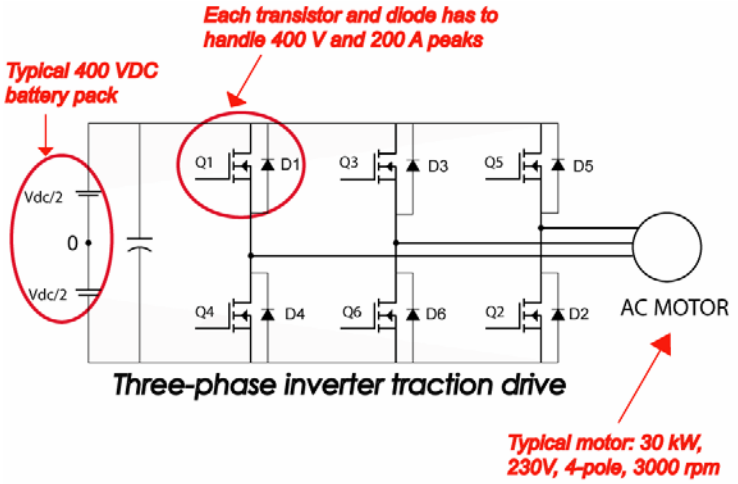
HEV Device addressable market - $5B

- Typical DC-DC converter
  - High voltage (400v) to 12V &/or 42V.
  - Typical power rating: 3 to 10kW
  - 10 devices



Isolated full-bridge step-down dc-dc

- Typical Inverter (DC-AC 3-phase converter)
  - Integrated motor/controller capable of delivering at least 55 kW of power.
  - 12 devices



Three-phase inverter traction drive

Total devices per vehicle ~ 34

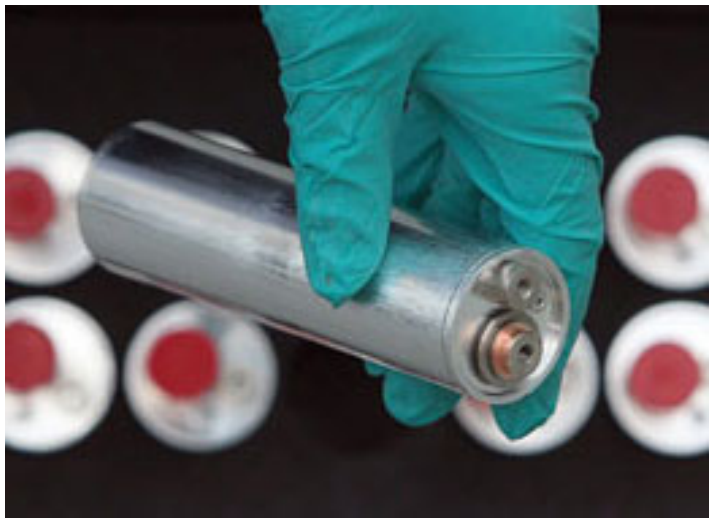
15M vehicles pa by 2015 ~ 50% hybrid/electric

Total addressable market =

255 million devices p.a. @ $20 asp

HEV Device addressable market - $10B

- Typical lithium battery pack
  - 100 cells
  - 4 devices per cell
  - Total devices per vehicle ~ 400
  - 15M vehicles pa by 2015
  - ~ 50% hybrid/electric



Total addressable market =

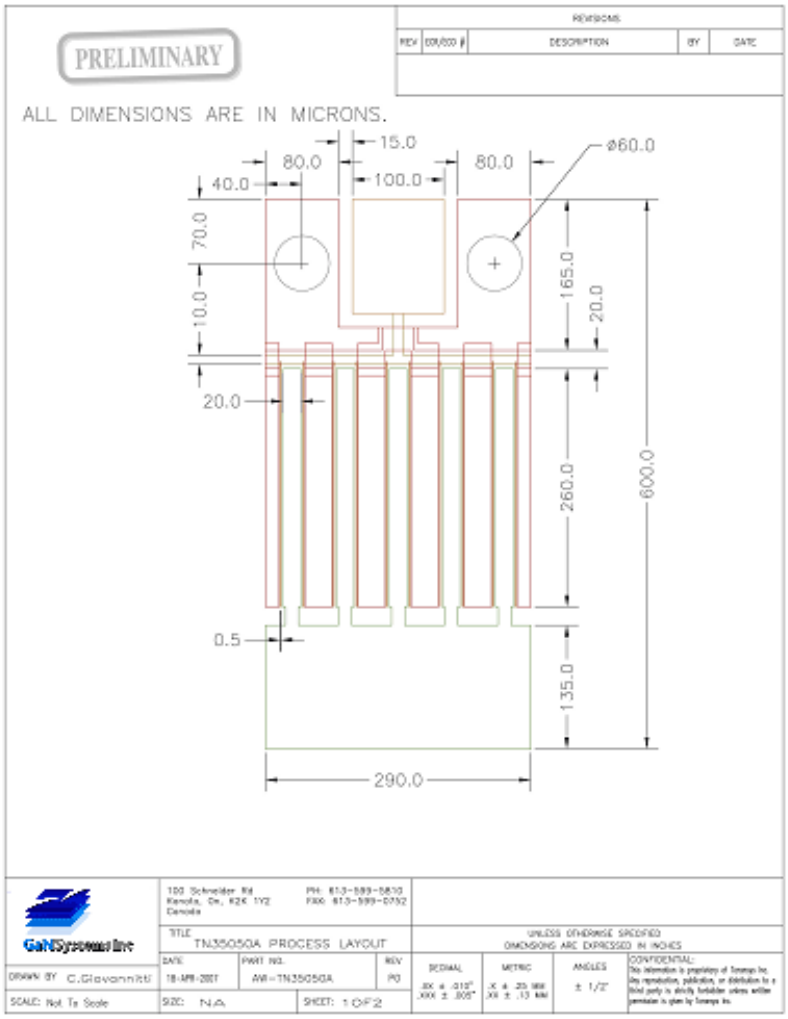
3 billion devices p.a. @ 10-40 cents per amp

Competition

	Program announced	GaN on Si	Current range	Voltage range	Samples	Production
Velox/ST	2007	Yes	10A	600v	?	No
IR	2008	Yes	100A	300v	Q4 2009	2011?
Sanken	2008	Yes	20A ?	?	?	?
Fuji/Furukawa	2009	Yes	?	600v	2010	2011
Fujitsu	2009	Yes	?	?	?	?
GaN Systems	2009	Yes	2-200A	100-600v	Q4 2009	Q4 2010

Milestones

June 2009	Provisional patent filing complete
Sept 2009	Target device specs
Dec 2009	Prototype silicon wafers processed
Q2 2010	First product sales
Q3 2010	20 qualified device types available
Q1 2011	First normally-off GaN transistor on the market
Q2 2011	4kW HEV converter demonstrated



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Gallium Nitride – the future of power semiconductors